

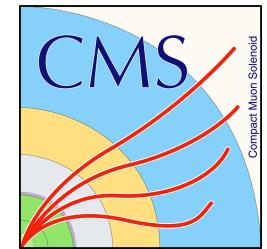
# Module Testing of CMS Forward Pixel Upgrade

Xuan Chen

THE  
**UNIVERSITY OF**  
**ILLINOIS**  
**AT**  
**CHICAGO**



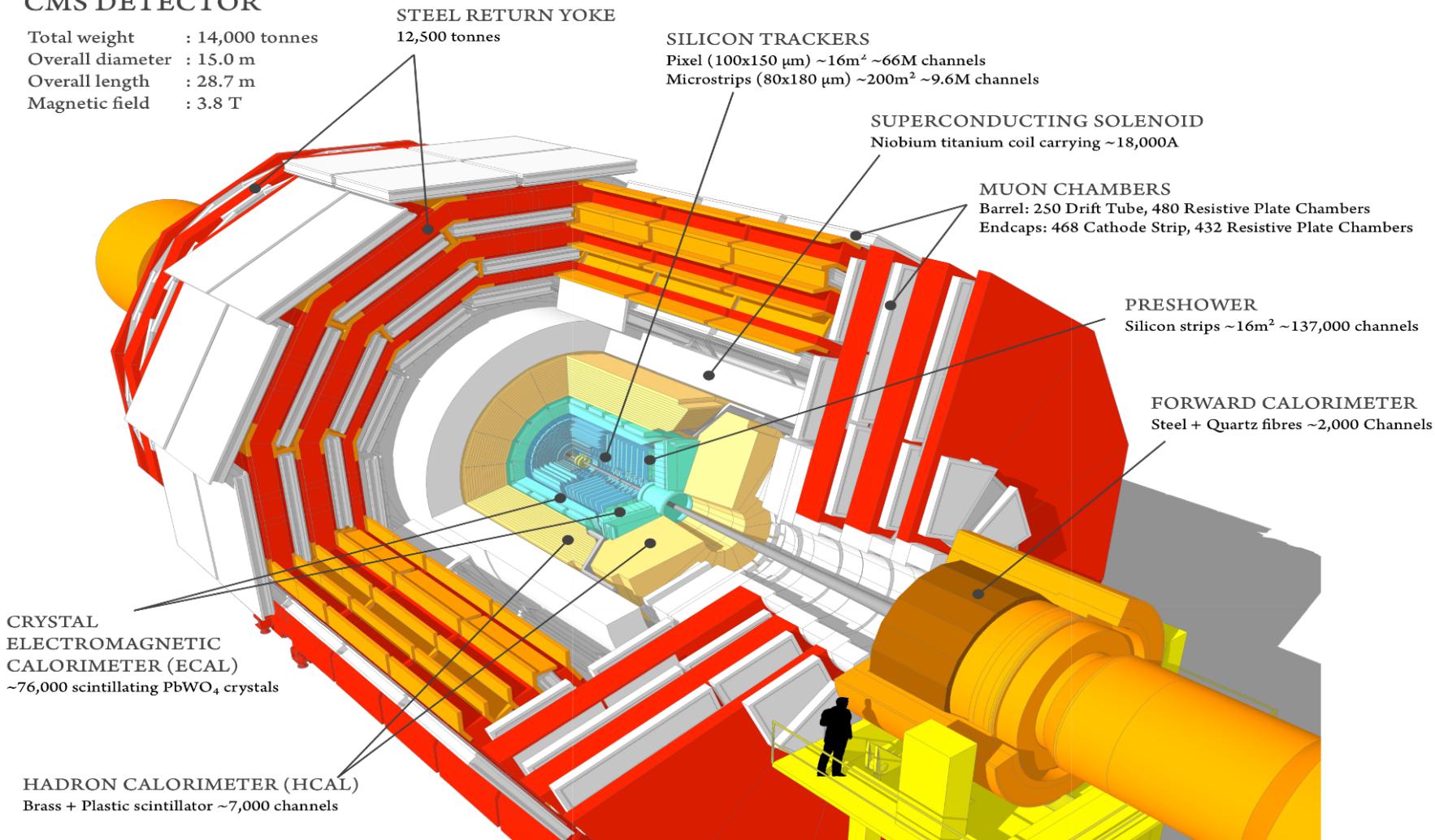
On behalf of the CMS Collaboration



# The Compact Muon Solenoid

## CMS DETECTOR

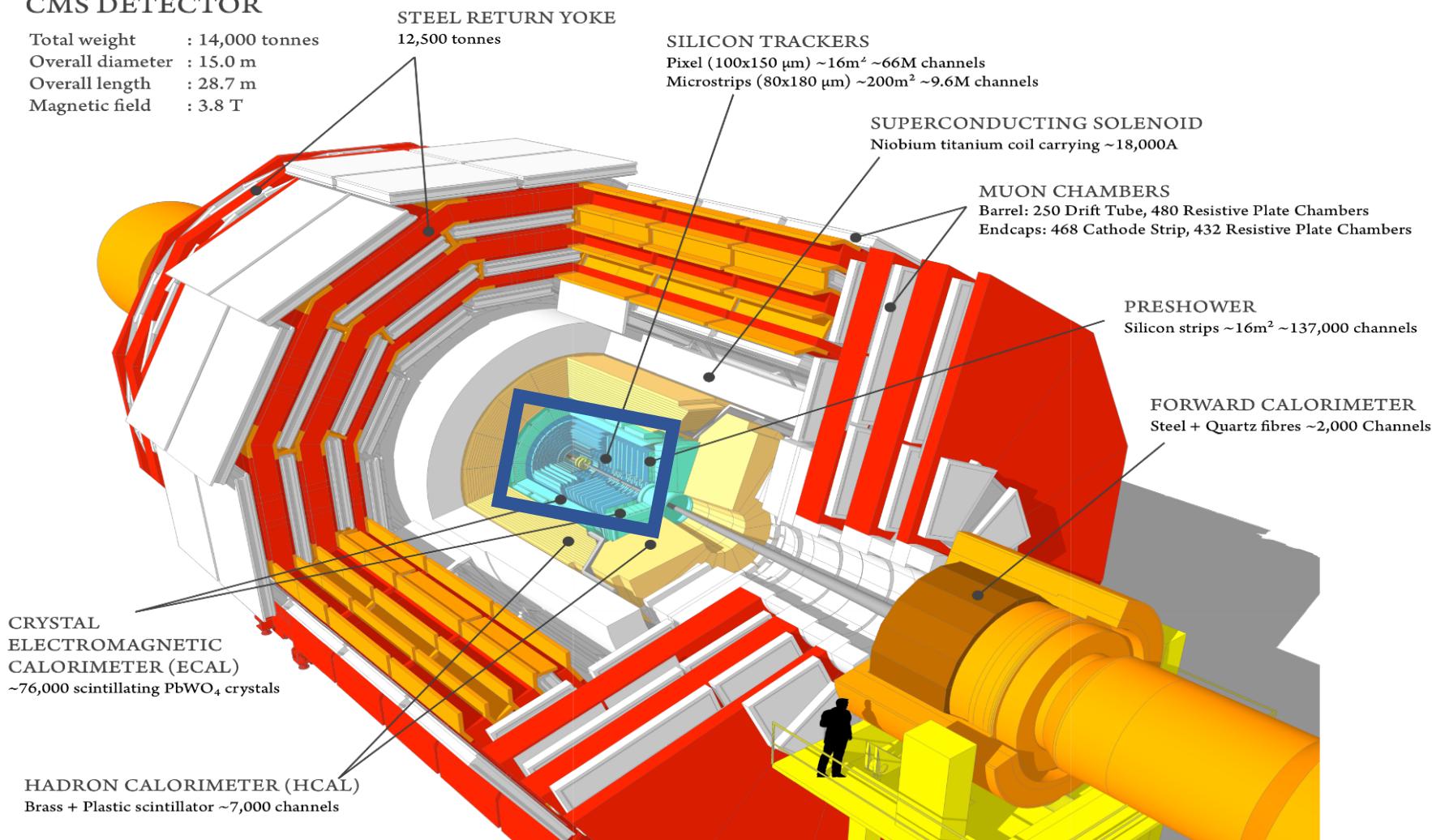
Total weight : 14,000 tonnes  
 Overall diameter : 15.0 m  
 Overall length : 28.7 m  
 Magnetic field : 3.8 T



# The Compact Muon Solenoid

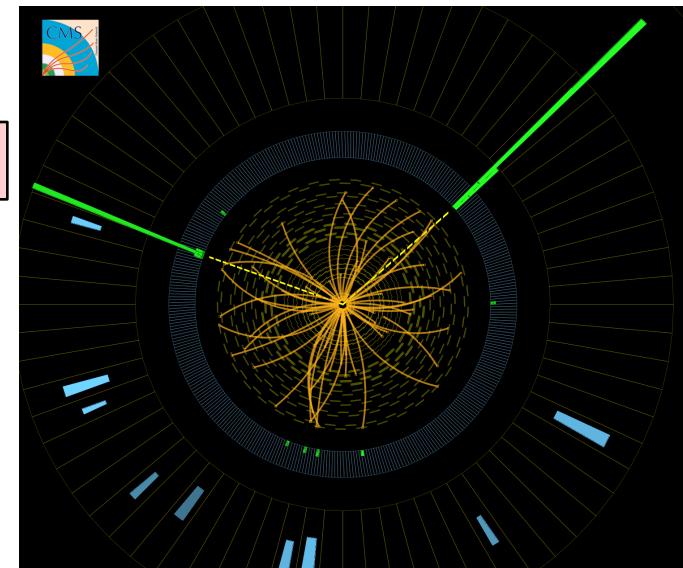
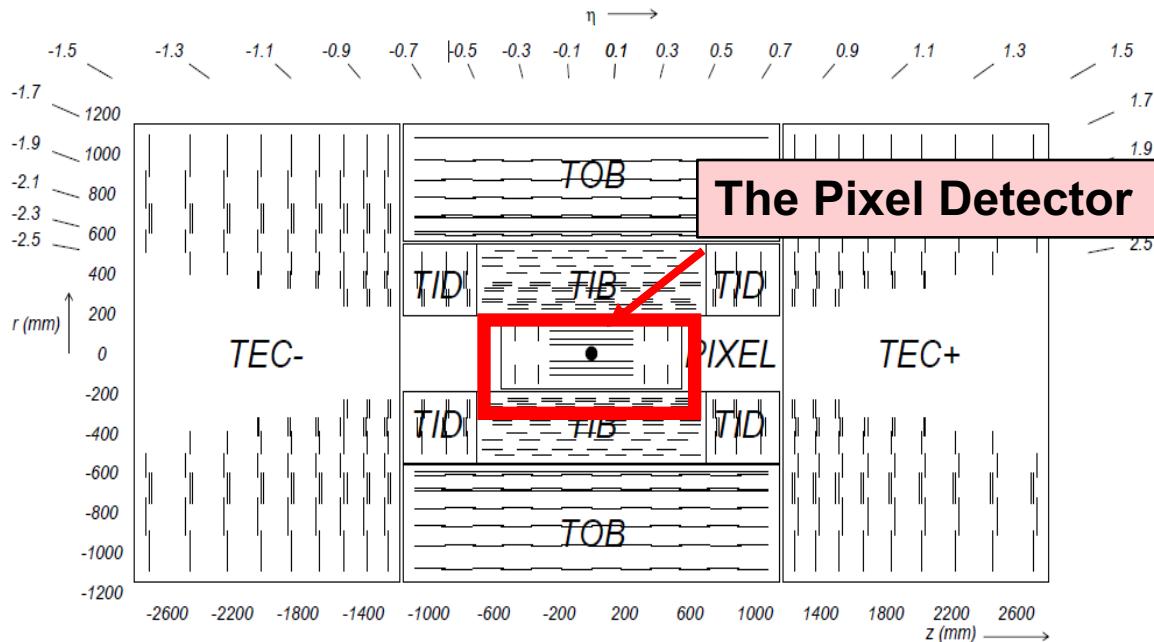
## CMS DETECTOR

Total weight : 14,000 tonnes  
 Overall diameter : 15.0 m  
 Overall length : 28.7 m  
 Magnetic field : 3.8 T



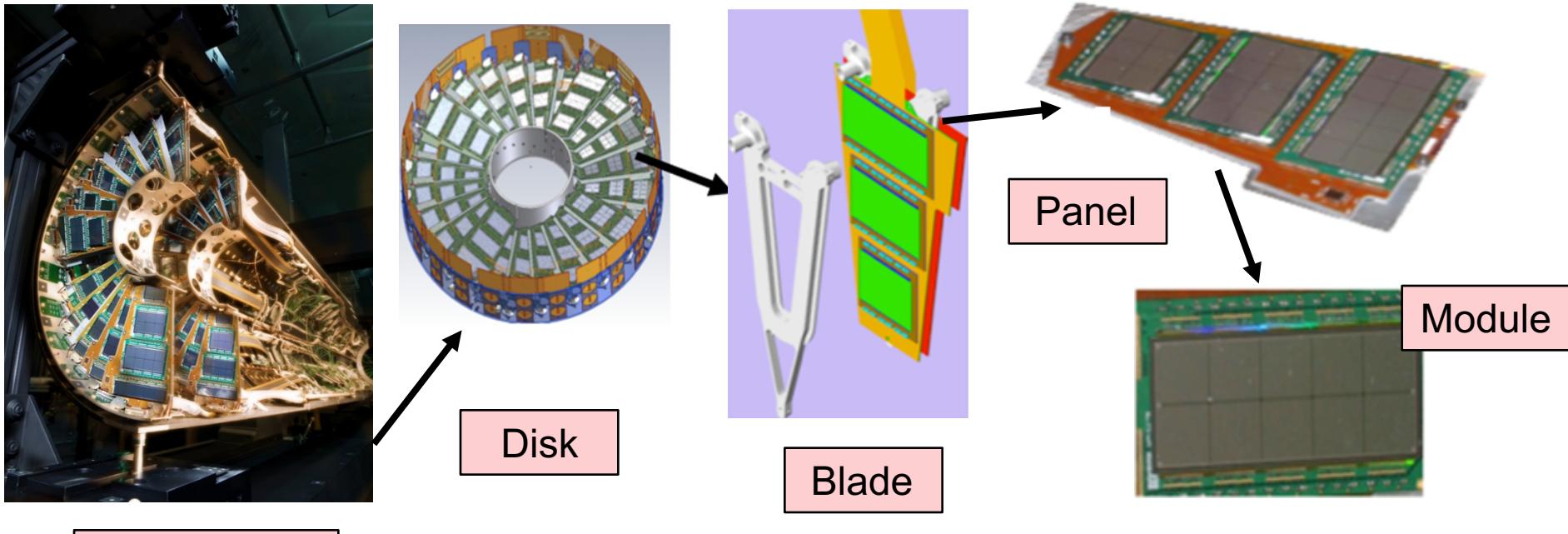
# Silicon Tracker

- Responsible for recording the trajectory of charged particles and measuring their momenta



- Pixel Detector:**
- 3 Barrel Pixel Layers (BPIX), 2 x 2 Forward Pixel Disks (FPIX)
- Si Strip Tracker:**
- 4 Inner Barrel Layers (TIB), 6 Outer Layers (TOB)
  - 3 x 2 Forward Inner Disks (TID), 9 x 2 Outer Disks (TEC)

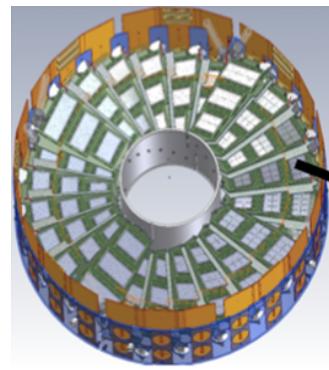
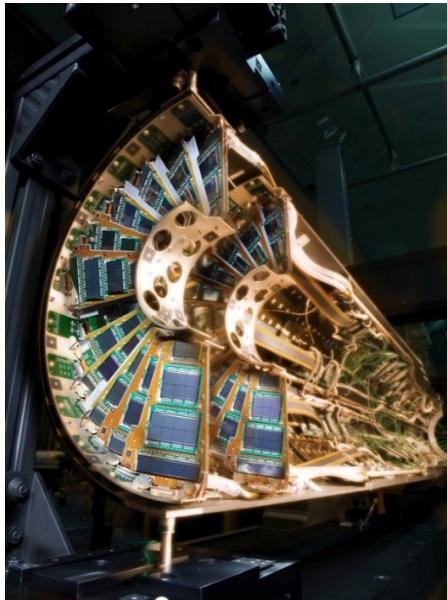
# The Forward Pixel Detector – Phase 0



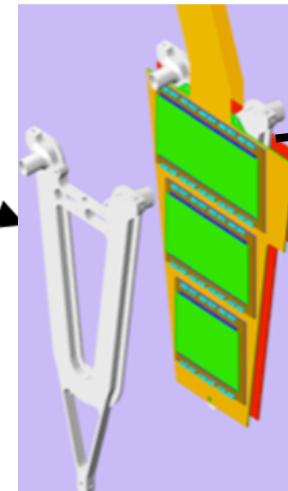
## Half Cylinder

- Provides precise track and vertex reconstruction
- Made of silicon with 18 million pixels
- Position resolution of  $\sim 10 \mu\text{m}$
- 40 MHz analog readout
- 4 Forward/Endcap Disks (FPIX)
- Populated with 672 pixel modules, with five different types

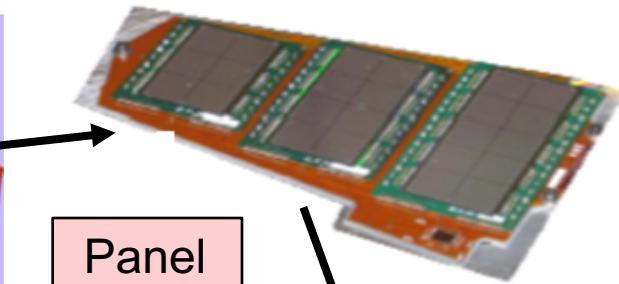
# The Forward Pixel Detector – Phase 0



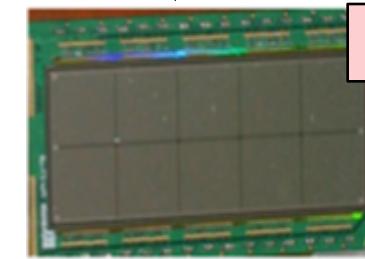
Disk



Blade



Panel



Module

## Half Cylinder

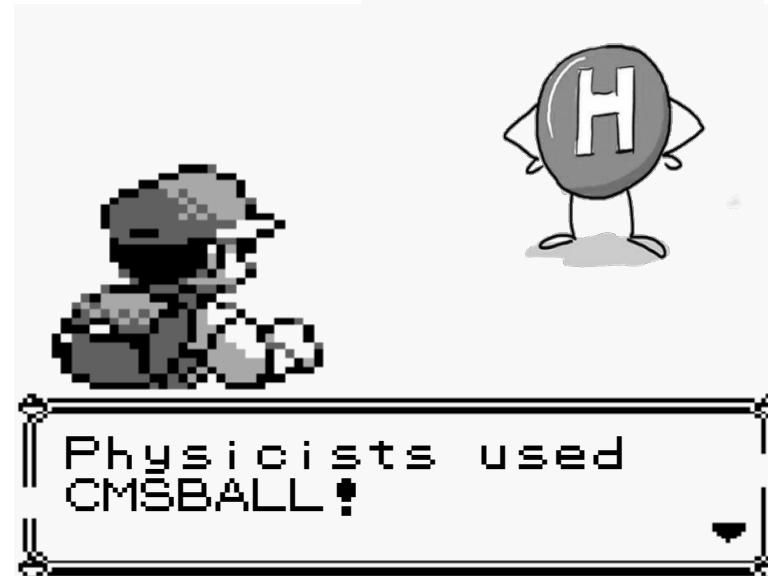
- Provides precise track and vertex reconstruction
- Made of silicon with 18 million pixels
- Position resolution of  $\sim 10 \mu\text{m}$
- 40 MHz analog readout
- 4 Forward/Endcap Disks (FPIX)
- Populated with 672 pixel modules, with five different types

6/13/16

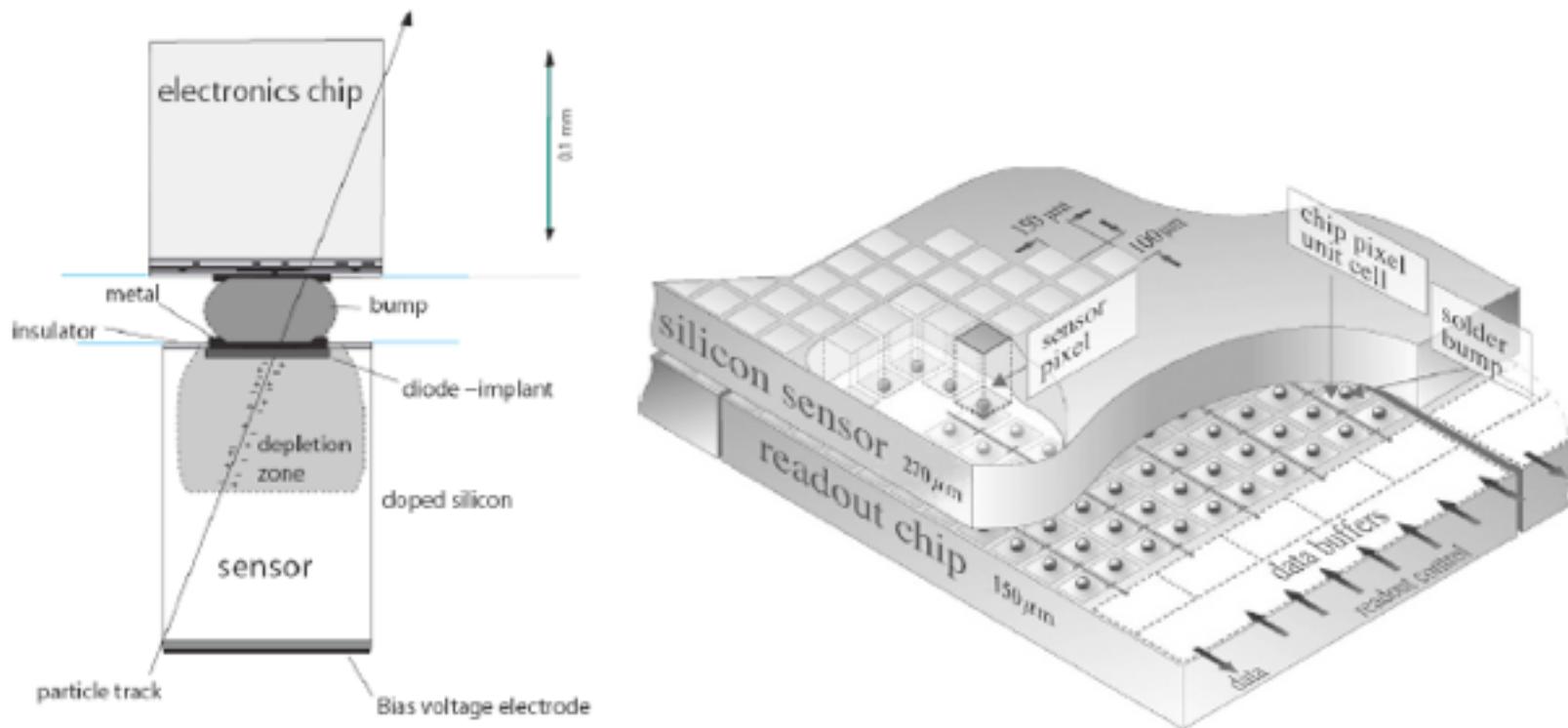
X.Chen New Perspectives 2016



# How Does the Detector Work



# How Does the Detector Work

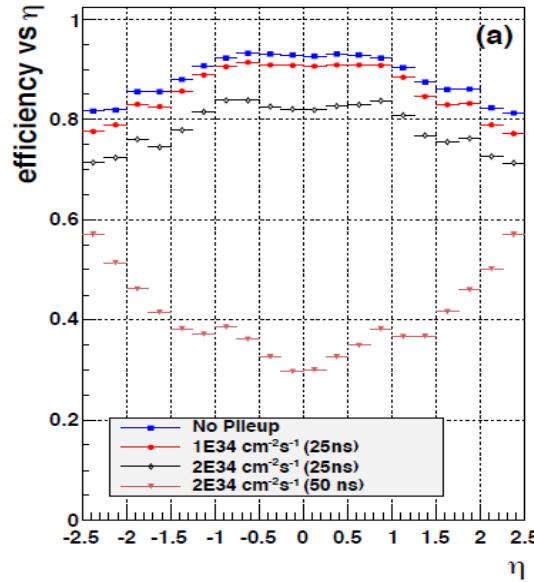


- When particle pass through the silicon, it will generate electron-hole pairs
- The electron-hole pairs will be separated and drift to the electrodes by E-field

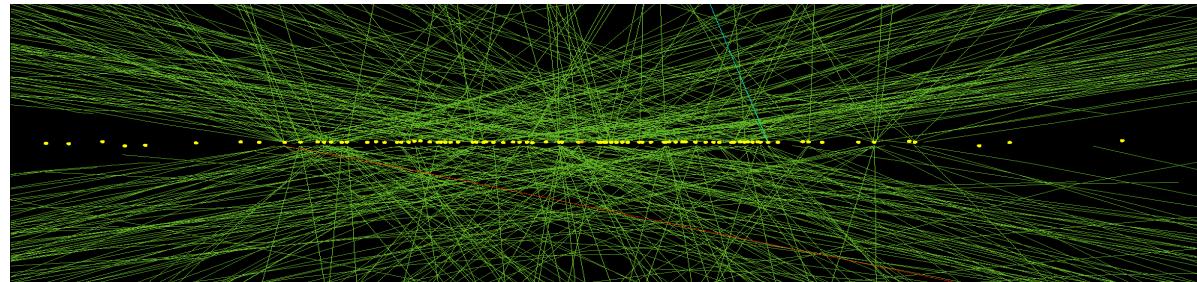
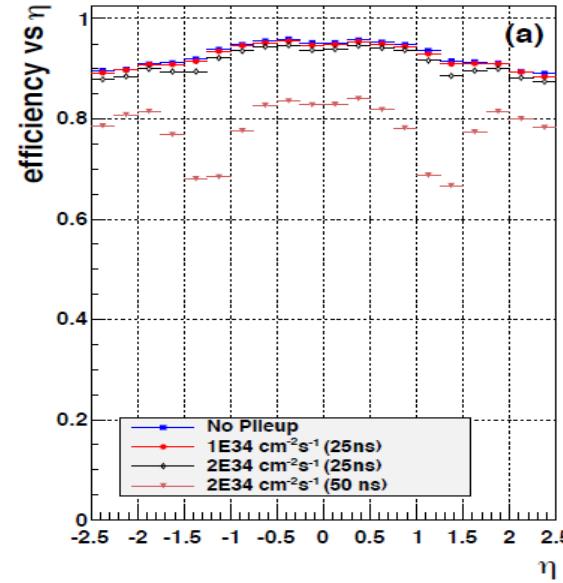
# The LHC Run II

- Increased energy and luminosity offer unique potential for historic discoveries
- But also brings new challenges to us

Current Detector



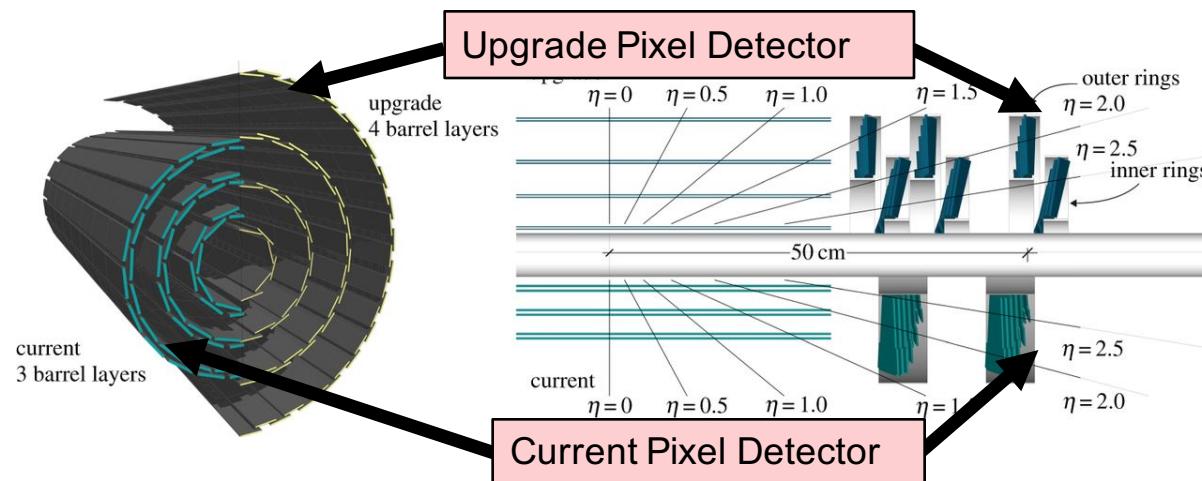
Upgrade Detector



Extreme pile-up conditions

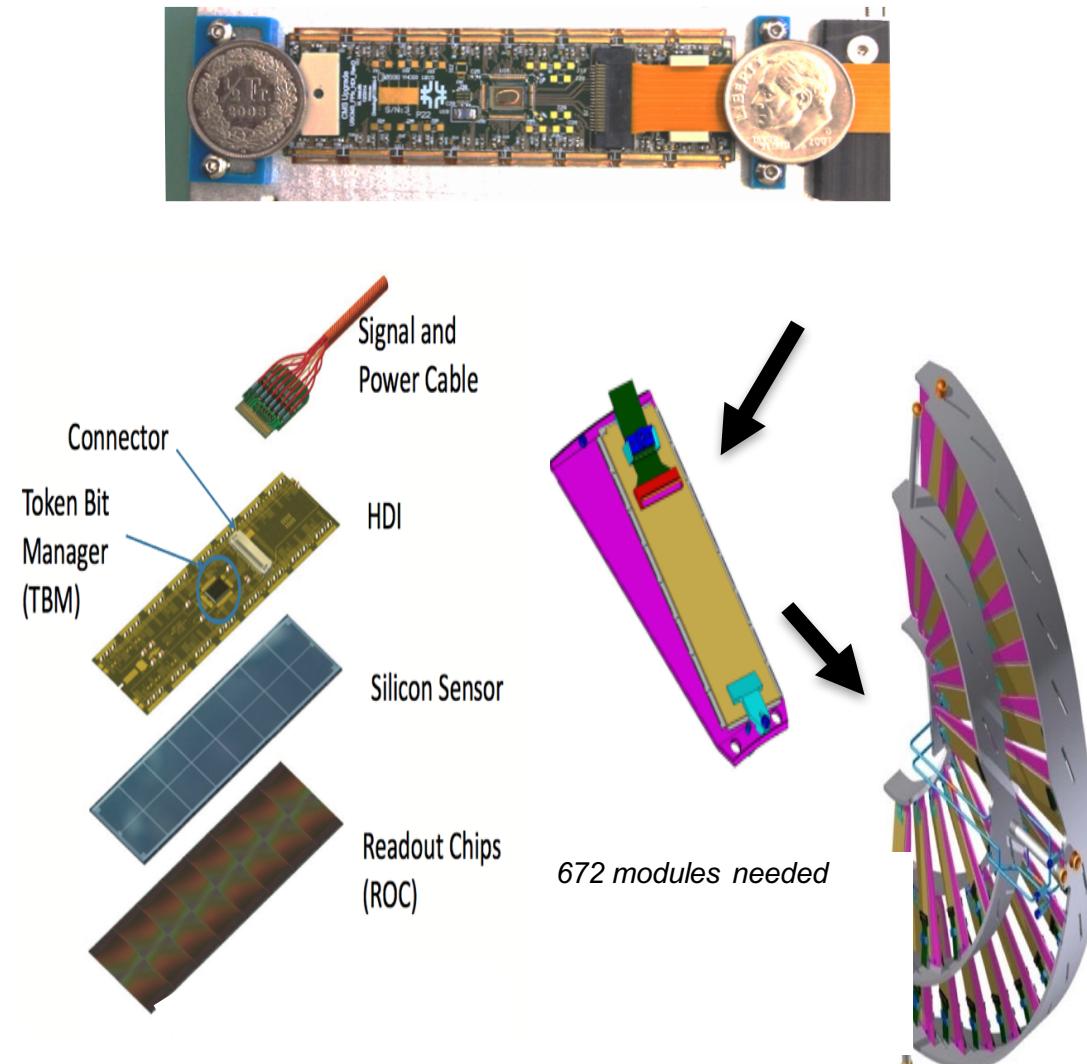
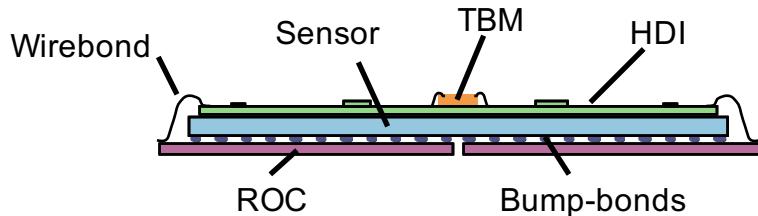
# The Pixel Detector – Phase I Upgrade

- Optimized detector layout for 4-pixel-hit coverage over the full tracker acceptance
  - Barrel layers from 3 to 4; Forward disks from 4 to 6
- Reduced material budget
  - New cooling system based on two-phase CO<sub>2</sub>
- New pixel readout chip (ROC) and token bit manger (TBM), digital readout (400MHz)
- The number of pixel will increase from 18 million to approximately 45 million in FPIX, and from 48 million to 79 million in BPIX
- Improved pattern recognition and track reconstruction



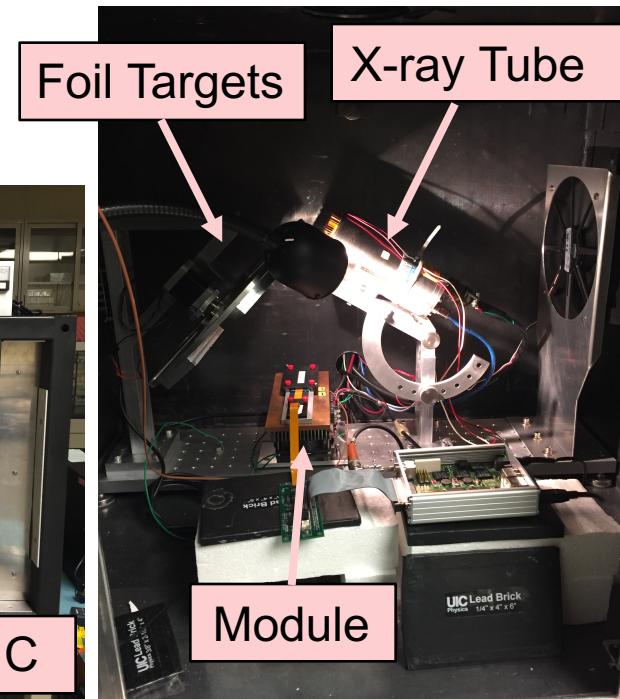
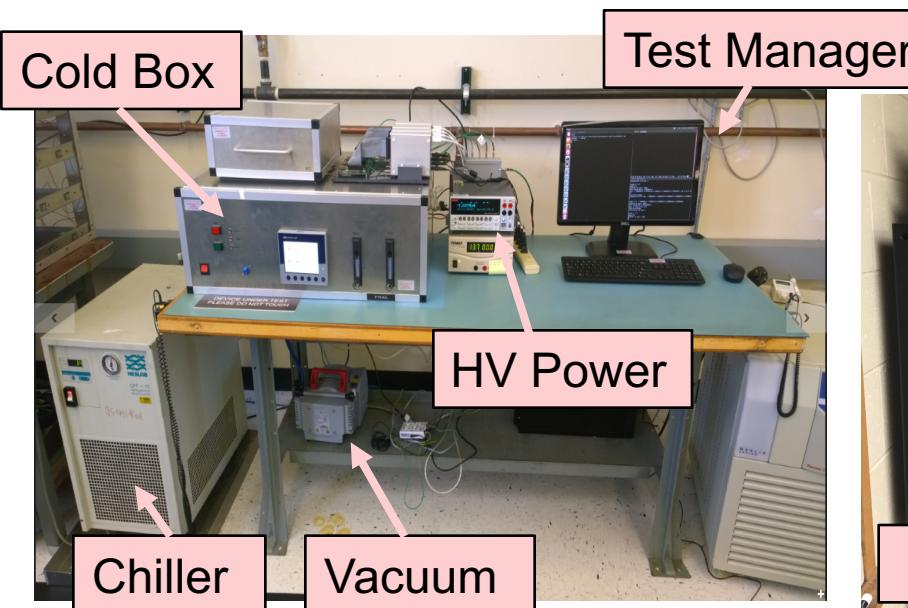
# The Pixel Detector – Phase I Upgrade

- Silicon sensor is bump bonded to ROC
- High Density interconnect (HDI) is glued to top
- ROCs are connected to HDI via wire bonds
- Token Bit Manager (TBM) is glued to HDI and connected via wire bonds
- Module is mounted onto carbon fiber half-disks



# Module Testing & Qualification

- Modules full calibration and debugging are performed at Fermilab and assembly sites
- Two stations with cold boxes
  - Test 4 modules in parallel
  - Test 8 modules / day (average)
- Finish testing ~1200 modules around September 2016
- X-ray testing is performed at UIC and KU

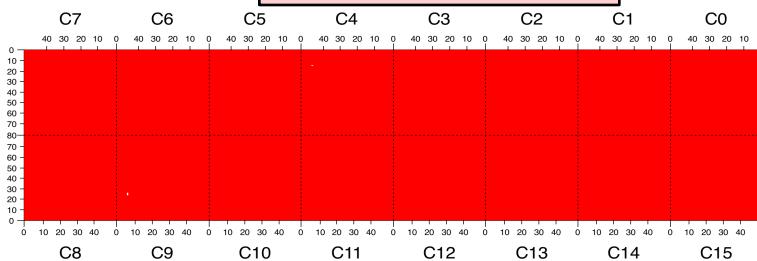




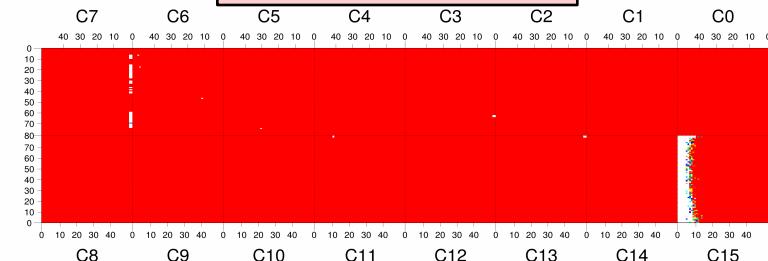
# Module Full Calibration



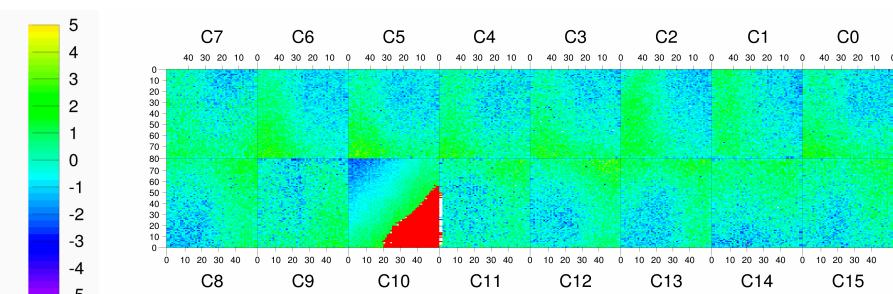
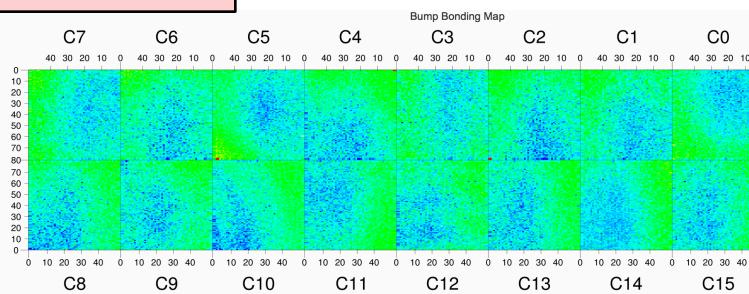
Good Module 😊



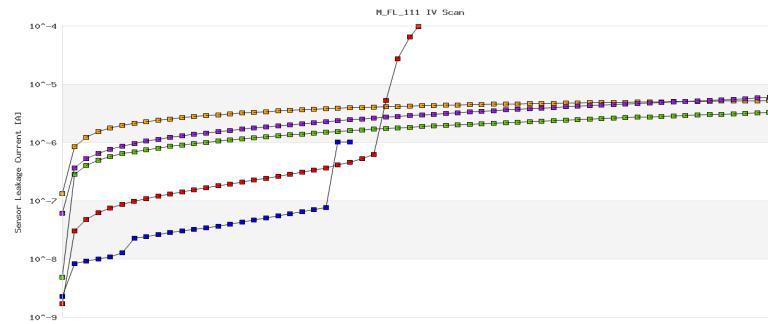
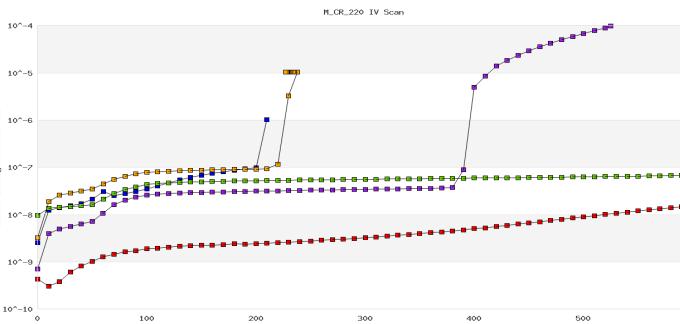
Bad Module 😥



Pixel Alive



Bump Bonding

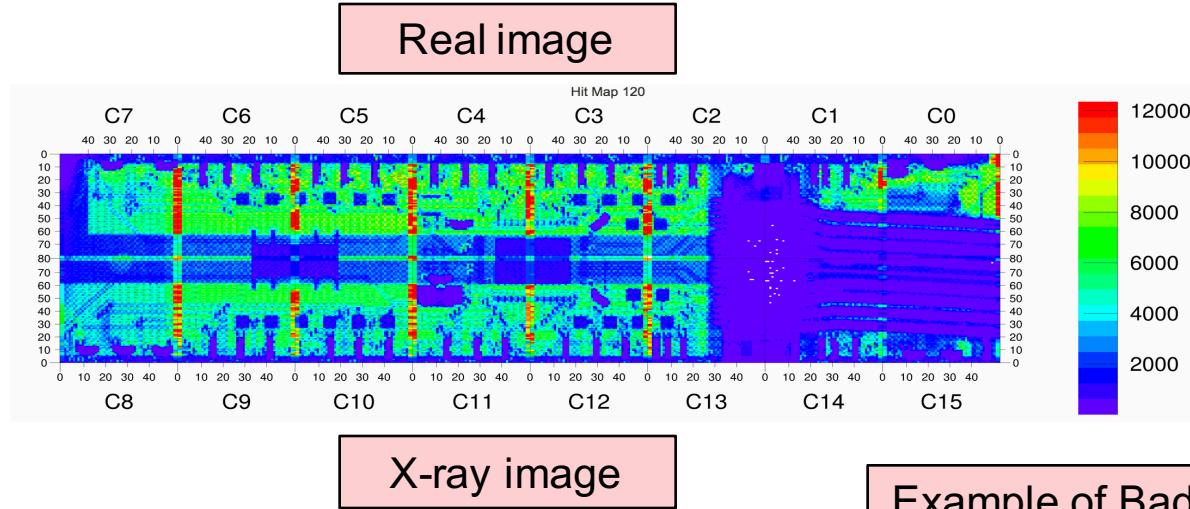


IV Scan

0/15/16

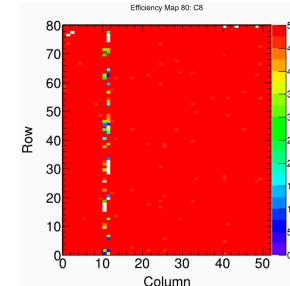
Additional tests described in the backup

# X-ray Testing



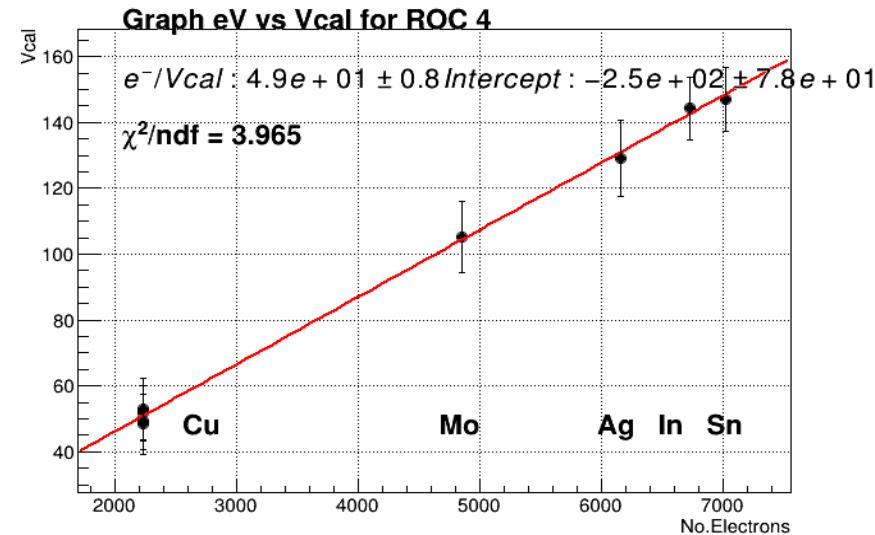
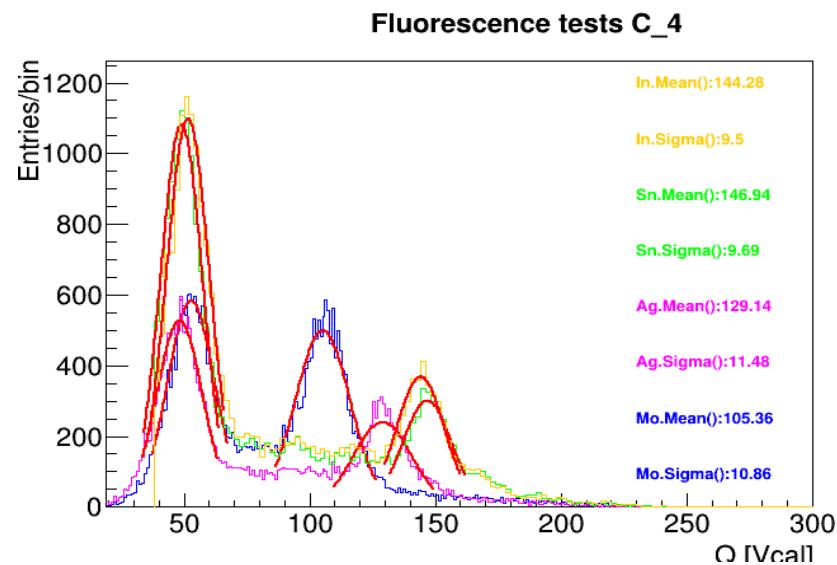
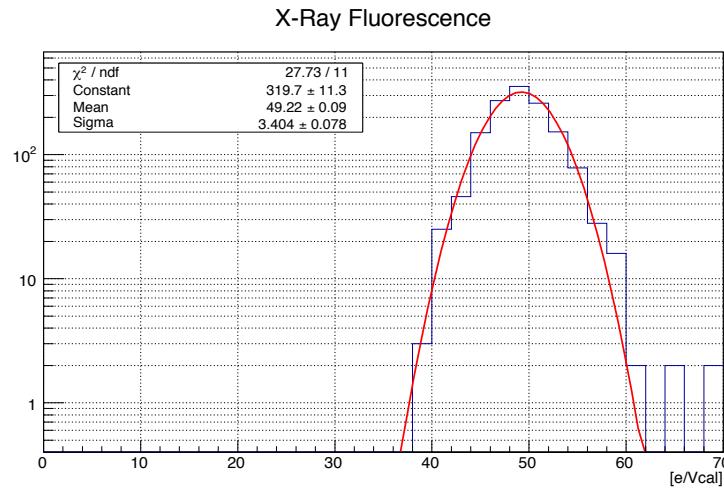
- The high-rate test will measure the double column efficiency at three different rates
  - High rate test will be performed on every single module
  - If there are more than one Double Column has efficiency lower than 95%, the module will be rejected

**Example of Bad Double Column**

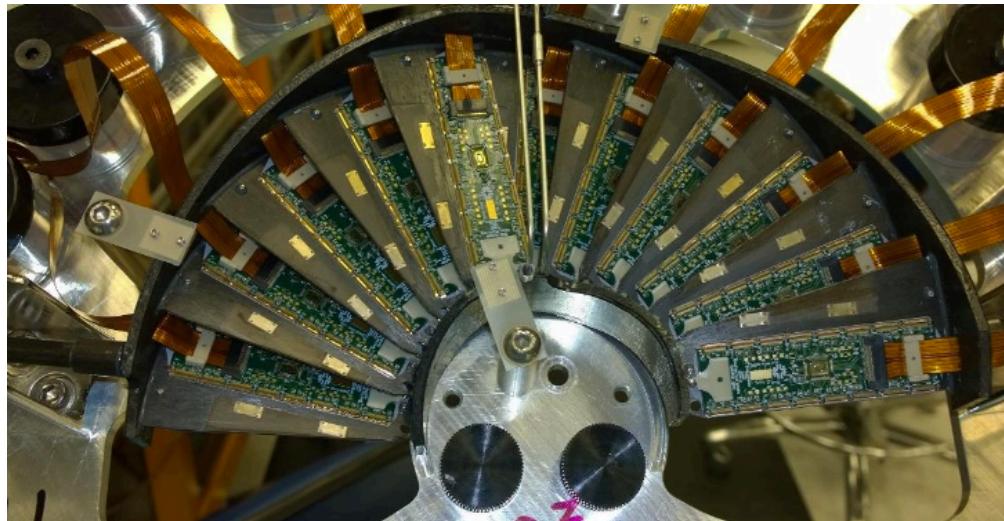
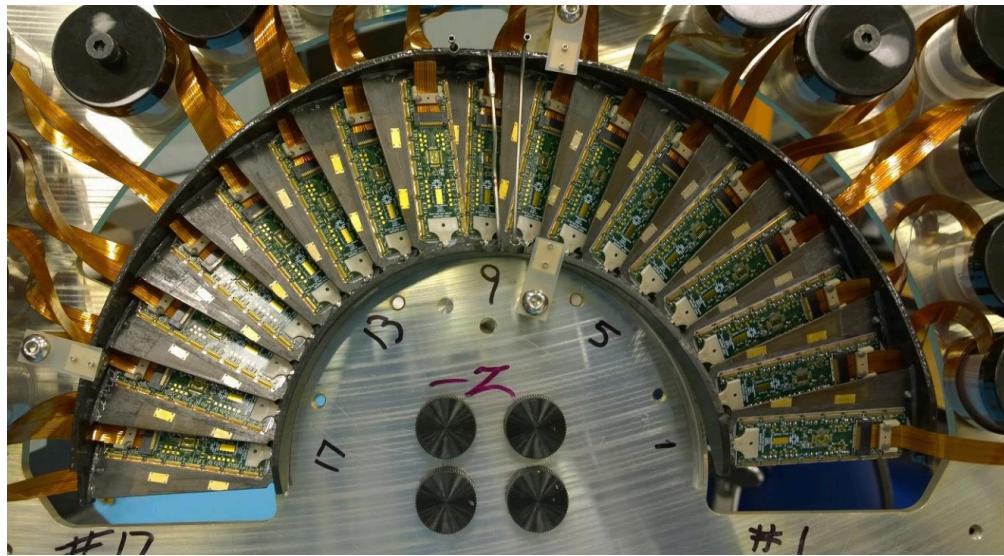


# X-ray Testing

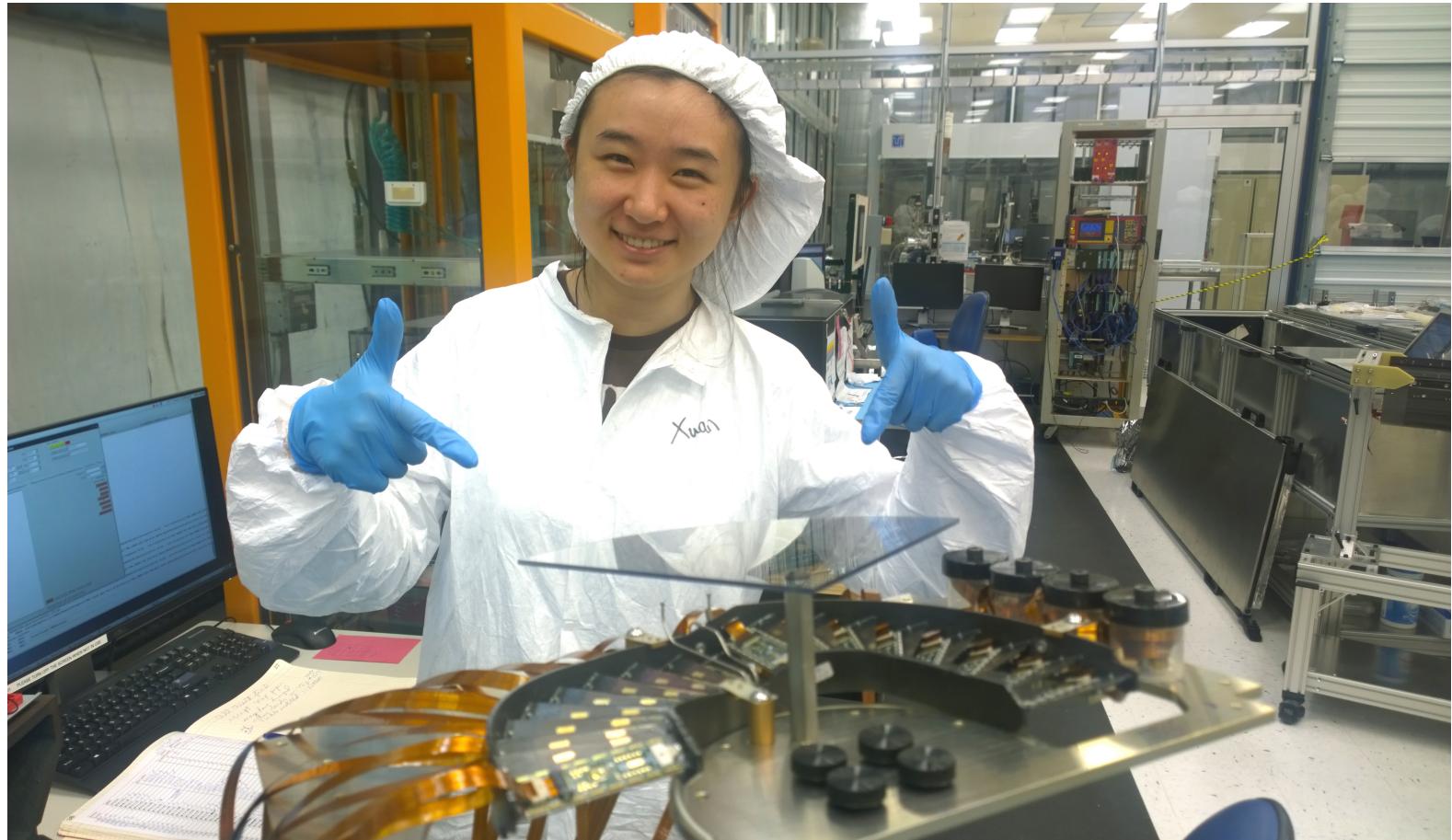
- Absolute energy calibration
  - Measure the performance of each module with X-Rays with 5 different energies
    - Cu, Mo, In, Ag, Sn
- Has been ran on all early modules
- Only Ran this test on one module per wafer (~50%)



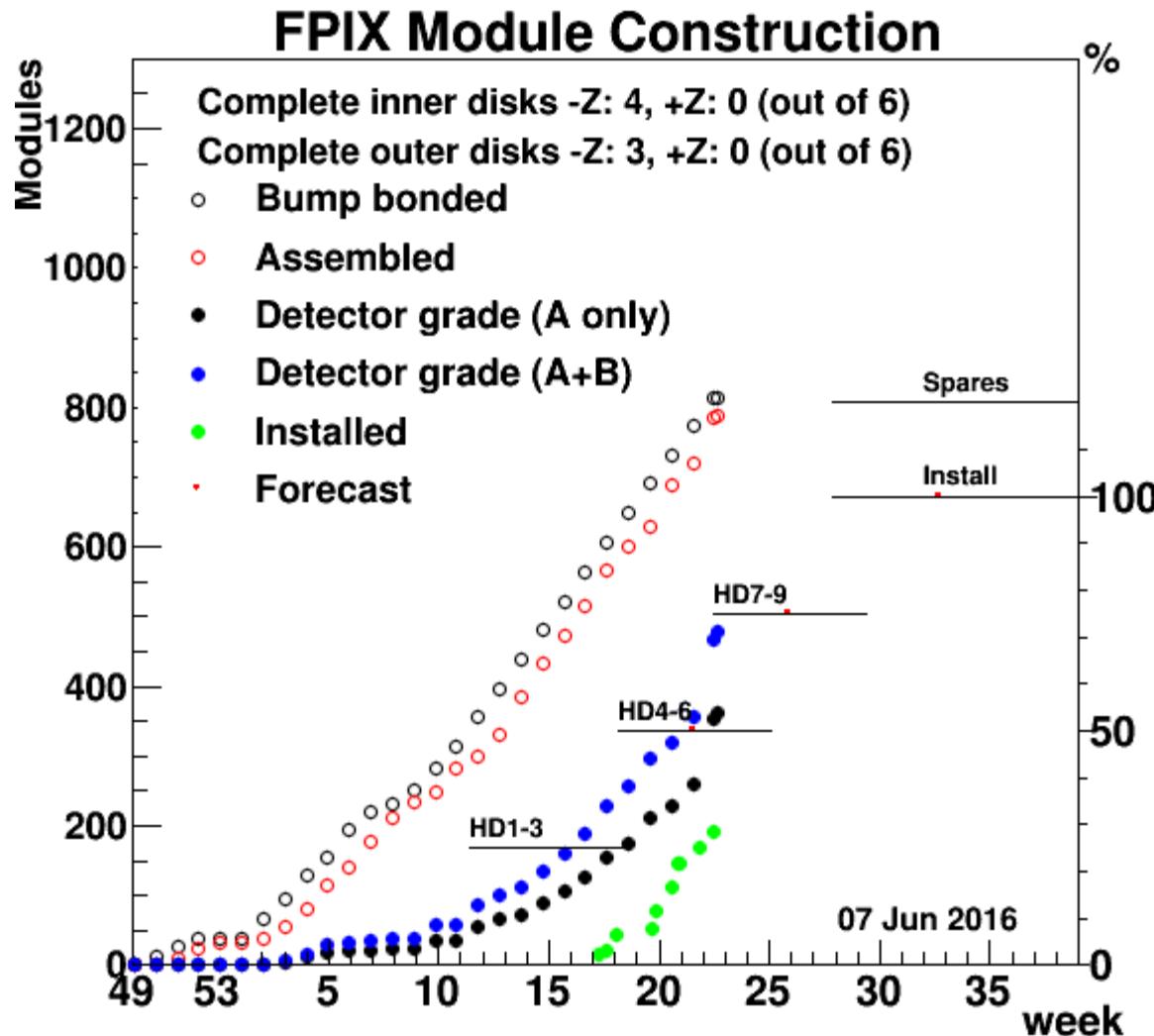
# First Half Disk!



# Half Disk!



# Assembly Over Time



# Summary

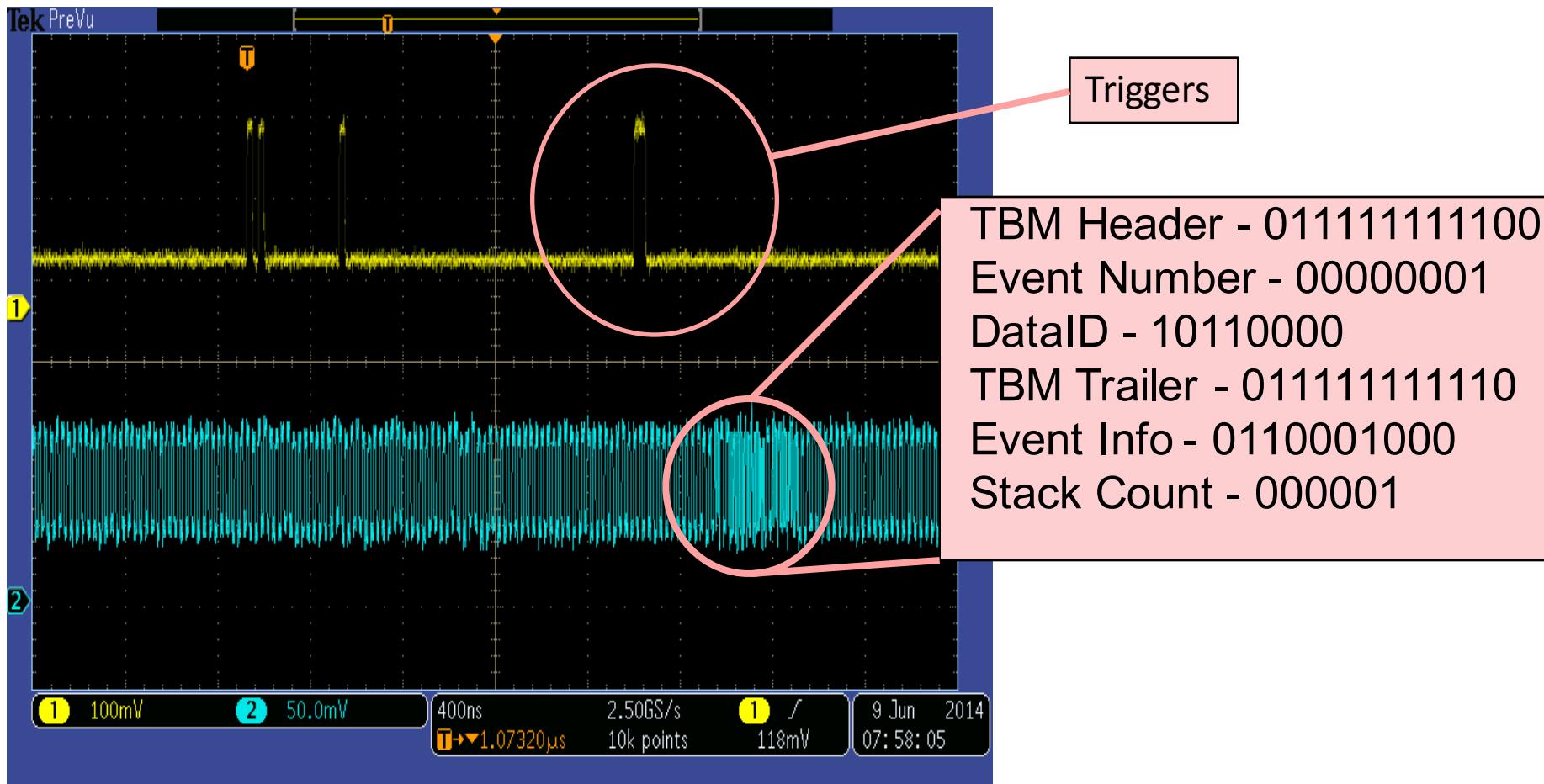
- The current pixel detector performs well under LHC Run I conditions
  - Under future run conditions will experience performance degradation
- An upgraded pixel detector is under construction to be installed in the winter of 2016/2017
  - Will maintain the current performance under extreme pileup conditions
- Module testing and qualification will be done by September 2016



# Backup

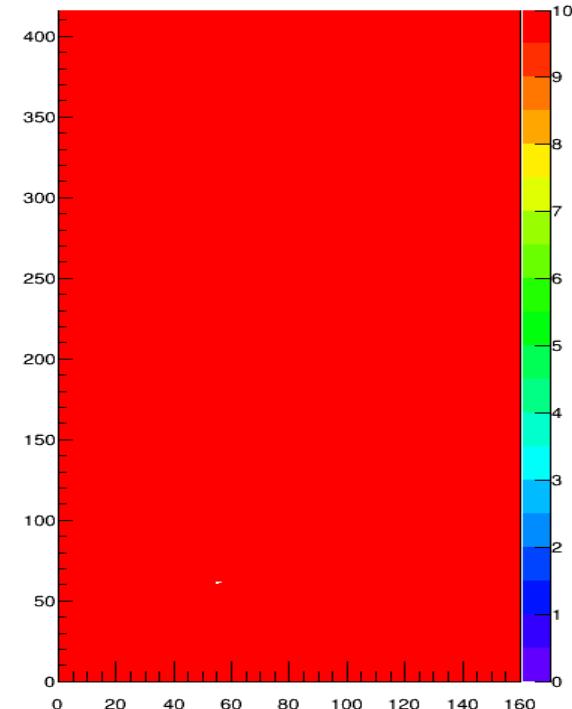
# TBM Decoding Test

- The TBM decoding test issues a single trigger to the TBM



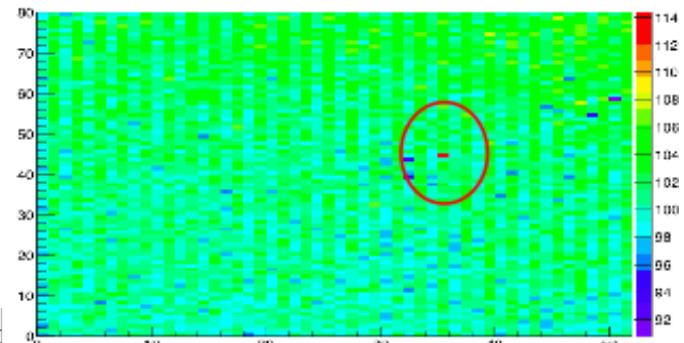
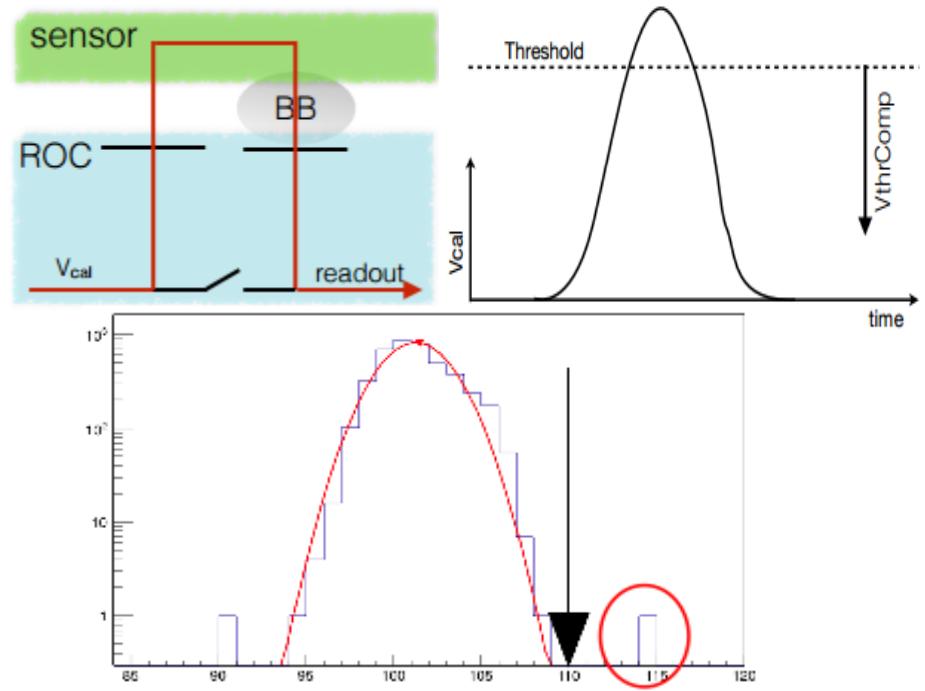
# Pixel Alive Test

- Pixel alive is a three-fold test that measures the functionality of the pixel unit cell
  - Inject calibration charge 10 times and measures the number of hits
  - Inject calibration charge into each individual pixel and verify that the correct pixel responds
  - Check that pixels can be masked



# Bump Bonding Test

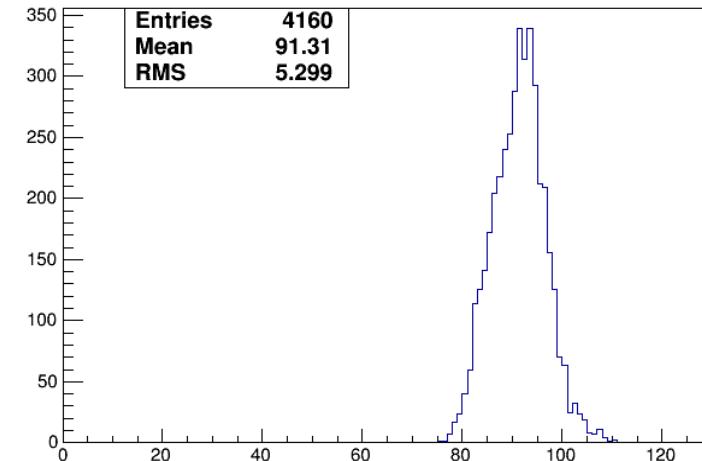
- Send fixed calibration charge into sensor
- Scan over the comparator threshold
- Generate efficiency curve vs. the comparator threshold
- Fit efficiency to extract turn-on value
- Fit Gaussian to bulk of this distribution, flag pixels with high turn-on as bad



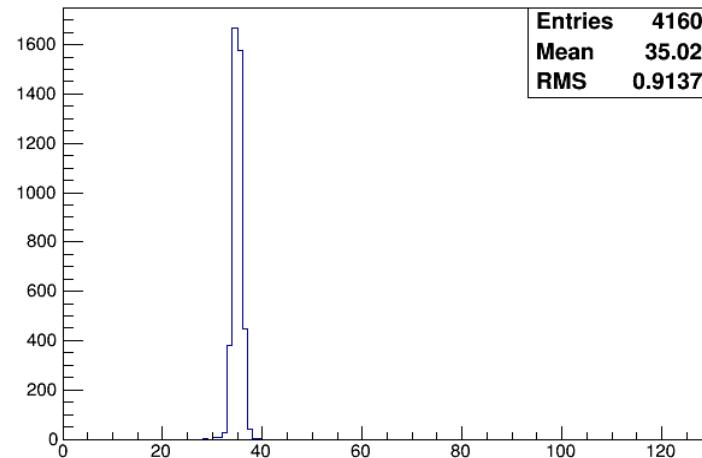
# Trim Test

- The trim test consists of two different test that **unify the pixel response across all ROCs**
  - RMS of threshold distribution should not exceed 400 e<sup>-</sup>
- The trim test sets the VThrComp and VTrim of each ROC
- The trim bit test sets 4 trim bits for each pixel.
- The goal of this process is to provide the narrowest turn on for a target VCal.

dist\_thr\_scurveVcal\_Vcal\_C0\_V0



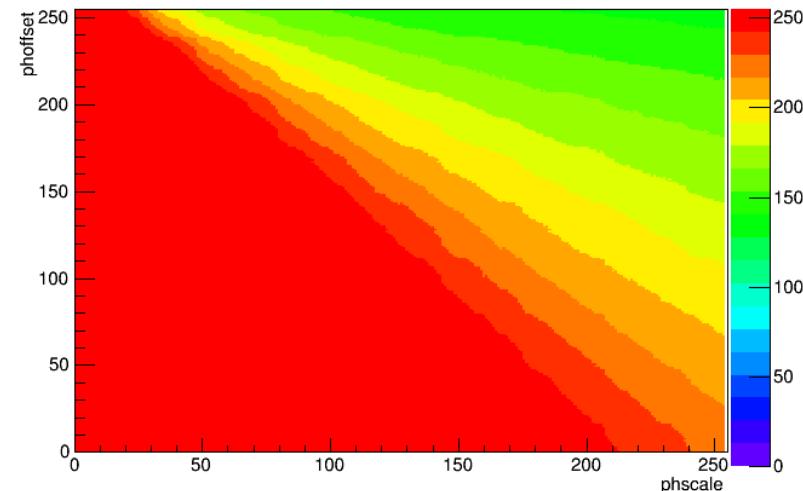
dist\_thr\_scurveVcal\_Vcal\_C0\_V0



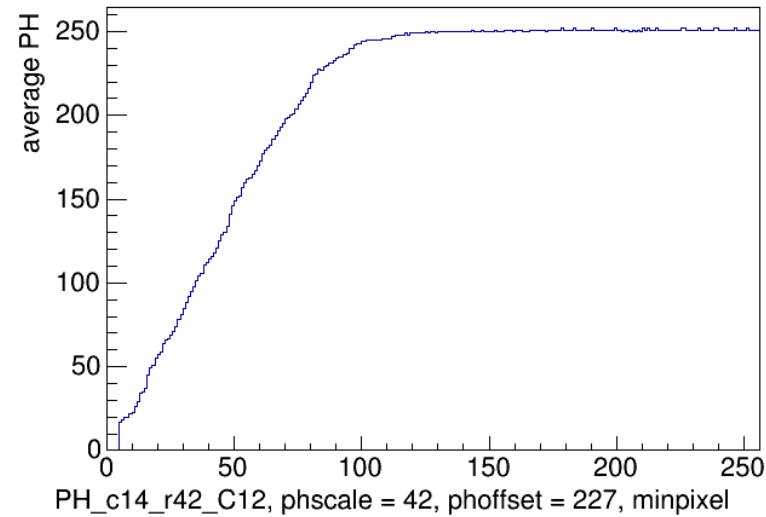
# Pulse Height Optimization

- Establish the dependency of the pulse height on the injected charge
- Phscale and Phoffset are scanned, and the point where the pixel amplifier saturates at the target Vcal is selected

max PH phscaleVSphoffset, C14

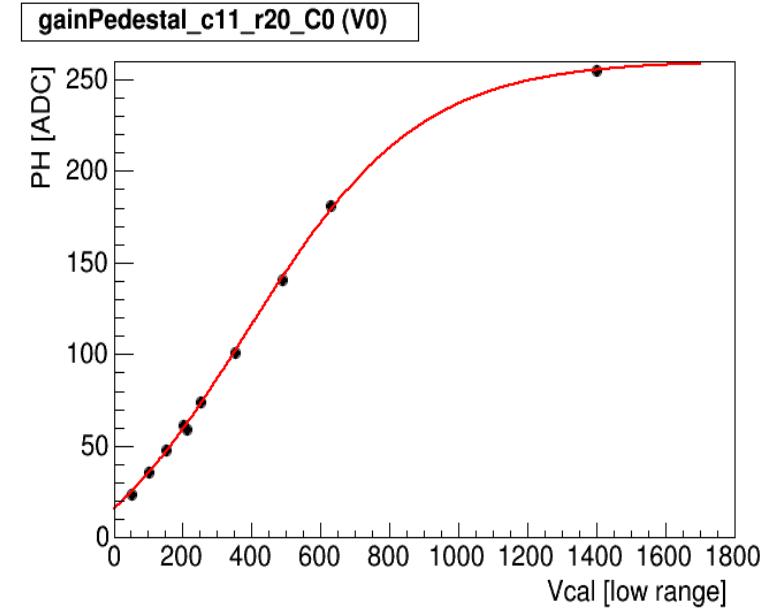


PH\_c14\_r42\_C12 (V0)



# Gain Pedestal Test

- The gain pedestal test measures the response of each pixel
  - Ensure linearity
  - Tolerate up to 20% variation of the gains
  - Pedestal RMS is required to be less than 5000 e<sup>-</sup>
- This is done by measuring the pulse height vs. injected VCal and fitting the response curve
- Once the gain pedestal test is finished, the module is fully calibrated and ready for X-ray tests



$$P_3 + P_2 \tanh(P_0 x - P_1)$$

# S-curves Test

- The S-curves test measures the performance of a module as a function of a single dac parameter
- Once a module is fully calibrated, a VCal S-curve will measure the performance of the trim and the **pixel noise**
- Noise should not exceed 1000 e<sup>-</sup>

`dist_sig_scurveVcal_Vcal_C0_V0`

